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MANPRINT Support of Aquila, the Army's Remotely Piloted Vehicle: Lessons Learned

John E. Stewart II, Edwin R. Smootz, and Nigel R. Nicholson
U.S. Army Research Institute

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Technical review by

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John L. Miles, Jr.

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The U.S. Army Research Institute (ARI) Systems Research Laboratory (SRL) supports the Army's manpower and personnel integration (MANPRINT) initiative in the testing and development of new systems. Operational Testing II (OT II) of the Aquila Remotely Piloted Vehicle revealed disappointing system performance thought to be due in part to manpower, personnel, training, and human factors problems. The SRL MANPRINT Task Force, headed by the Fort Hood Field Unit, was asked by Headquarters Training and Doctrine Command and the U.S. Army Field Artillery School to help identify the problems and recommend ways to resolve them. The SRL Task Force examined operator and maintainer MANPRINT concerns (e.g., target detection, mission planning, and maintenance manpower) and was able to recommend concrete ways to minimize the impact of these problems on total system performance.

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John E. Stewart II, Edwin R. Smootz, and Nigel R. Nicholson
U.S. Army Research Institute

Manned Systems Group
John F. Hayes, Chief

Systems Research Laboratory
Robin L. Keesee, Director

U.S. Army Research Institute for the Behavioral and Social Sciences
5001 Eisenhower Avenue, Alexandria, Virginia 22333-5600

Office, Deputy Chief of Staff for Personnel
Department of the Army

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Human Factors in Training
and Operational Effectiveness

FOREWORD

The Systems Research Laboratory (SRL) of the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) supports the Army's MANPRINT (Manpower and Personnel Integration) initiative in the testing and development of new systems and new MANPRINT methods such as HARDMAN II (Hardware vs. Manpower) analysis.

This report discusses the joint effort of two SRL organizations, the Fort Hood Field Unit and the Manned Systems Group, to identify and resolve major manpower, personnel, and training (MPT) difficulties that reduced the effectiveness of the Army's Remotely Piloted Vehicle, Aquila. The effort was undertaken in response to requests from Headquarters, Training and Doctrine Command (TRADOC), and the U.S. Army Field Artillery School (USAFAS) in August 1987. In June 1988, a memorandum and a working paper describing the work reported herein were sent to USAFAS (the original proponent for Aquila), the program manager, the TRADOC systems manager, and the U.S. Army Intelligence Center and School (the proponent for the Unmanned Aerial Vehicle (UAV) program).

This report emphasizes lessons learned from this MANPRINT intervention that may be applied to the successor of Aquila, the UAV. By applying lessons in this way, key MPT issues and concerns can be addressed early in the acquisition process and performance of future systems enhanced.

The results of this project were presented at the 30th Annual Conference of the Military Testing Association in November 1988. Although Aquila was cancelled in early 1988, the lessons learned from this ARI effort were incorporated into the System MANPRINT Management Plan for the UAV.

Edgar M. Johnson

EDGAR M. JOHNSON
Technical Director

MANPRINT SUPPORT OF AQUILA, THE ARMY'S REMOTELY PILOTED VEHICLE: LESSONS LEARNED

EXECUTIVE SUMMARY

Requirement:

Many manpower, personnel, and training (MPT) problems were discovered during testing and development of Aquila, the Army's Remotely Piloted Vehicle (RPV). A U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) Systems Research Laboratory (SRL) manpower and personnel integration (MANPRINT) Task Force, coordinated by the Fort Hood Field Unit, was asked by Headquarters Training and Doctrine Command and the U.S. Army Field Artillery School to help resolve these MPT problems.

Procedure:

The SRL Task Force conducted an in-depth evaluation of the major MPT issues relating to operation and maintenance of the RPV. Among these issues were an analysis of specific human performance problems uncovered during Operational Testing II (OT II), an extensive review of the literature on imaging systems, and a sensitivity analysis applied to the results of the original hardware vs. manpower (HARDMAN) analysis to incorporate lessons learned from OT II.

Findings:

The SRL Task Force was able to identify major MPT problems and to suggest concrete ways in which their impact on total system performance could be minimized. Most of the recommendations suggested MPT solutions to the problems.

Utilization of Findings:

Although the Aquila was cancelled in early 1988, the lessons learned from this MANPRINT intervention have provided valuable insights into the MPT issues that must be addressed and resolved before a new system is built. Much of this guidance is being incorporated into the System MANPRINT Management Plan for the Unmanned Aerial Vehicle, a family of systems technologically similar to Aquila.

MANPRINT SUPPORT OF AQUILA, THE ARMY'S REMOTELY PILOTED VEHICLE: LESSON LEARNED

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MANPRINT SUPPORT OF AQUILA, THE ARMY'S REMOTELY PILOTED VEHICLE: LESSONS LEARNED

Introduction

Background

Aquila, the Army's Remotely Piloted Vehicle (RPV), is a relatively small unmanned aircraft that is remotely controlled from a ground station and is designed to carry a payload that can serve target acquisition, designation, reconnaissance and surveillance functions. Development of the system can be traced back to 1971 when the Defense Science Board recommended that the Army establish a program which would apply mini-RPV technology to the fire support functions of target designation and adjustment of artillery fire. The concept of using pilotless aerial vehicles for military purposes was investigated as early as World War I, albeit with little success (Joint Electronic Warfare Center, 1986). It was looked at again in World War II, and has been under some degree of research and development ever since. Much of the early success was with fairly large target drones which simulated flying aircraft and were used for gunnery exercises. Eventually, the idea of modifying such drones by hanging cameras on them emerged, and this combined with evolving technology created many possibilities for military application. For example, the development of the electronic digital computer, progressive miniaturization of components, and other related developments in the 1960s and 1970s, provided the possibilities for building relatively small air vehicles which could continuously send real time digitized data to a ground station. In addition, it allowed controllers to control actively the flight path or permit the air vehicle to follow a preprogrammed flight path of relatively long duration. Finally, such small vehicles could be easily launched and recovered, and for some requirements procured cheaply enough to be expendable.

It was in this technological milieu, combined with an increasing concentration of Soviet ground-based air defense weapons posing a high threat to piloted reconnaissance aircraft, that the Defense Science Board made its recommendation in 1971 to develop mini-RPVs for reconnaissance and target acquisition. In September, 1974, the program formally got underway when the U.S. Army Training and Doctrine Command (TRADOC) and the U.S. Army Materiel Command signed a letter of agreement to develop an RPV system that could demonstrate how RPVs could be used by ground commanders in reconnaissance, target acquisition, laser designation of targets, and adjustment of artillery fire. This effort evolved into the development of a prototype system which came to be known as Aquila and underwent three series of tests: Development Test (DT) II in 1985-1986, (Cozby, 1986), Operational Test (OT) II in 1986-1987 [U.S. Army Operational Test and Evaluation Agency (OTEA), 1987], and Force Development Test and Experimentation (FDTE) in late 1987 [U.S. Army TRADOC Test and

Experimentation Command (TEXCOM), 1988]. Following the conclusion of the FDTE, the Army decided to halt further development and cancelled acquisition plans for Aquila. The Army's RPV efforts have since been combined with those of the other military services under a Joint Program Office for Unmanned Aerial Vehicles (UAV), and the few Aquila systems that were initially built for test and evaluation purposes are currently serving as a test bed for the joint program.

MANPRINT

Manpower and personnel integration (MANPRINT) is a new Army initiative whose goal is to optimize total system performance by considering the soldier as an integral part of the system. In order to accomplish this goal, issues and concerns relating to manpower, personnel, training, human factors engineering, health hazards and system safety must be addressed early in the development of a system. In this way the potential adverse impact of these factors on soldier and system performance can be minimized.

The Army Research Institute (ARI) Systems Research Laboratory (SRL) supports the goals of MANPRINT in the testing, development, and acquisition of Army systems. This involves not only support of field testing but also the development and pilot-testing of analytical MANPRINT methods for potential users. The current project concerns itself with MANPRINT support to TRADOC provided by the SRL Aquila MANPRINT Task Force. The ARI Fort Hood Field Unit was responsible for technical direction of the current project, and had previously provided MANPRINT support of OT II. The ARI Manned Systems Group was asked to provide technical assistance in addressing MANPRINT concerns pertinent to Aquila's imaging system, and to demonstrate how procedures for estimating maintenance manpower requirements could be improved. The ARI Fort Bliss Field Unit provided technical support in addressing cognitive workload issues.

Lessons learned from this intervention were incorporated into recommendations of manpower, personnel and training actions that should serve partially to ameliorate some of the problems that had threatened to diminish the performance of Aquila and those unmanned aerial systems that will succeed it.

The extensive testing and evaluation that Aquila underwent during its multiyear development has provided the SRL MANPRINT Task Force with a great deal of useful information about how unmanned aerial systems should be designed, operated and maintained. The remainder of this report will focus on some of the MANPRINT problems and issues that were brought to light during this period. The first section will discuss three topics pertinent to operation of the system: (1) Target Acquisition, (2) Mission Planning, and (3) Manpower and Personnel Selection. The second will demonstrate how a representative MANPRINT method

developed by ARI can be employed as a useful tool for estimating maintenance manpower requirements. The results of the cognitive workload research will appear in a separate ARI report.

Operator-Related MANPRINT Concerns

Target Acquisition

One of the major findings of OT II was that Aquila crews too often failed to detect targets. Examination of the results from OT II (OTEA, 1987) indicates that overall detection rate was around 17% (24% of moving targets and 13% of stationary targets). Several uncontrollable extraneous factors contributed to this low detection rate. In addition, Aquila crews were required to search too large an area during the test. The mean area reconnoitered during OT II was 17.6 km^2, which exceeded the 16 km^2 area the Army considered to be the maximum for a typical three hour Aquila sortie (U.S. Army Field Artillery School, undated). It also became obvious during the test that searching for targets from an altitude of 1500 m with a 20° field of view is very much like looking at the world through a straw, and is a very difficult and tedious process.

Between the completion of OT II and the beginning of the FDTE, the Army reevaluated Aquila search requirements using data from OT II and experience learned from other systems and concluded that it was not feasible to search so large an area for targets in general. Instead, it seemed better to use other intelligence sources to indicate approximately where targets may be, and to use such information to cue Aquila crews to search a smaller area.

This change was incorporated into the operating procedures established for the FDTE. In addition, software was developed to assist the operator in performing reconnaissance (TEXCOM, 1988). A bookkeeping function was developed which automatically kept track of the area that had been searched. During OT II operators easily lost track of where they were when they took manual control of the system, thus making it difficult to search an area systematically. With the new bookkeeping function an operator could take manual control of the system, leave the area, perform an emergency search somewhere else, and, providing he did not enter a new waypoint, come back and automatically resume the search.

The other software improvement was an automatic search routine known as the step-stare technique. This technique focused on a given portion of the search area for a fixed amount of time, depending on the amount of clutter in the area, then automatically moved to and focused on an adjacent area with about a 10% overlap, and thus, provided for the systematic search of a whole area. This change increased the time required to search an

area, however, from 12 to 35 minutes per km^2. Consequently, the Army reduced its maximum area search requirement to 6 km^2 per sortie (U.S. Army Field Artillery School, 1987).

All of the above changes were incorporated into the Aquila system prior to the FDTE with the intention of increasing the target detection rate. The results of the FDTE were encouraging. Ninety-eight percent of all moving target arrays and 94% of all stationary arrays that were not camouflaged were acquired by the Aquila operators during the FDTE (TEXCOM 1988). However, no target arrays that were camouflaged were acquired. Thus, the results showed a definite ability to detect moving and stationary, uncamouflaged targets, and an inability to detect targets camouflaged with either artificial or natural material.

There were additional target acquisition problems which had been identified during the OT II, and still posed a problem during the FDTE. For example, operators found it very difficult to detect targets that were in shadows, as often happens when one camouflages a vehicle by parking it under or near a tree. Dr. Aaron Hyman (1987), recently of ARI, identified a potential contributor to this problem, along with a possible solution. Although the camera in Aquila was of very high quality, the circuitry associated with the automatic gain control and the automatic level control was designed to clip the upper and lower 10% of the illuminance falling on the photocathode. A linear transfer function described the relationship between the middle 80% of the photocathode illumination and the output signal that was transmitted to the ground control station and translated into various shades of grey on the video display. When an Aquila operator was searching a scene, the camera typically received a wide range of input luminances, the lower of which often came from dark or shadowy areas. Since the lower 10% of the input luminances was clipped, the information about objects in the shadows was not transmitted to the video monitors on the ground.

Dr. Hyman suggested a number of ways to solve this problem. A procedural solution would be to use a narrow field of view (FOV), such as 2.7°, to search shadowy areas so that the dynamic range of input luminance spans just the shadowy area. However, this is only feasible for short periods of time. Of the three Aquila FOV options, 2.7°, 7.2°, and 20°, operators tended to use the 7.2° and 20° FOV's much more than the 2.7° FOV because of the tremendous decrease in the amount of terrain they could observe through a narrow 2.7° FOV, and the corresponding increase in the amount of time needed to search an area. An engineering solution to this problem would be to provide the operator with the option of switching, as circumstances dictate, to circuitry which would not clip the lower input luminances and would employ a non-linear transfer characteristic with a high gain at the lower end of the input luminance distribution. This could be used to amplify and detect any signals that existed in shadows.

Forward Looking Infrared (FLIR) cameras are seen by many observers as another solution to this problem of detection of targets in shadows. However, it should be noted that FLIR, while having many advantages, does not always produce as clear a picture as one would like. When contrast between two objects is low, it is still difficult to distinguish them, and the Army currently plans to provide for both daylight TV and FLIR as potential payloads on its UAV system that is in the initial stages of development. Thus, the problem of detecting targets in shadows with daylight TV cameras is one which must be addressed.

Another aspect of the problem of detecting camouflaged targets concerns the combination of slant range and FOV for searching an area. Dr. Hyman's communication with various experts in the field of imagery analysis indicated that the acquisition of targets in clutter, such as vegetation, is a somewhat different process than in open terrain. In the latter situation an observer typically detects something, and then after obtaining better resolution by moving closer to it or magnifying it, recognizes it as a particular type of object. In clutter, however, it appears that detection of an object or target does not occur until resolution is sufficient to recognize it. Previous research (Johnson, 1958) has shown that <u>recognition</u> of military vehicles with a probability of 0.5 requires about eight (TV) lines of resolution. Thus in clutter, it appears that about eight lines of resolution are needed to detect a target. Dr. Hyman calculated that with Aquila's 7.2° FOV, a slant range of 1.66 km was required in order to obtain enemy target representation (e.g., a tank) of eight lines of resolution. However, Aquila doctrine suggested a 2.5 km slant range for area search with the 7.2° FOV. Thus, it is possible that some targets in clutter were not detected during testing of Aquila because adequate target resolution was not obtained at the video monitor due to the non-optimal combination of slant range and FOV.

One way to resolve this problem would be to use a narrower FOV. This would give more lines of resolution to a target of given size. Another alternative would be to use a shorter slant range, such as the 1.66 km slant range mentioned above, although this would require flying below that altitude which had been determined as the minimum for sustained survivability.

<u>Mission Planning</u>

Another problem uncovered during the OT II was that Aquila crews accepted from higher headquarters mission requests that exceeded the capabilities of the system (TEXCOM, 1988). This typically took the form of crews accepting a mission to search an area larger than Aquila could reasonably handle during a three hour sortie. The exact cause for this was not empirically determined, but it was thought to be due to several factors, to include lack of understanding of Aquila's limitations by the crews, and a tendency to be unquestioning when receiving mission

orders from a higher headquarters. As a result, the training program was modified prior to the FDTE to give Aquila crews training on system limitations and the need to resolve conflicts with higher headquarters over nonexecutable mission requests. During the FDTE crews were given ten incomplete mission orders and nine nonexecutable mission orders. They were scored on whether they resolved those conflicts. Scoring occurred in two ways. First, a subject matter expert (SME), a senior warrant officer observed the crews during the three phases of a mission (i.e., receiving the mission order at higher headquarters, planning the mission in the Ground Control Station, and executing the mission by flying the air vehicle and searching for targets) and judged whether or not they resolved mission request conflicts with higher headquarters (TEXCOM, 1988). Second, videotapes of crew actions during all three phases were scored by independent evaluators to determine the frequency and distribution of crew actions involving: a) requests for clarification of missions from higher headquarters, and b) explaining system capabilities to higher headquarters (Nicholson, Deignan, & Smootz, 1988).

The results were conclusive. The SME determined that crews identified and adequately resolved all 19 conflicts presented to them. The videotape analysis showed that this conflict resolution behavior was about evenly spread out over all three phases of mission execution. However, as a proportion of the communications activity occurring during each phase, it was found that it comprised most of the communication (88%) between Aquila crewmen and higher headquarters while receiving the mission, but only 8% of such communication during mission planning, and less than 1% during actual flight.

An implication of these findings is that specific training in system limitations is extremely important, especially given that searching an area with UAVs has proven to be a very slow and tedious process. Individuals in higher headquarters who are tasking UAVs may easily overestimate their search capability and it is crucial for UAV crews to be trained to expect this and be prepared to resolve such problems with higher headquarters.

Manpower and Personnel Selection

The third topic related to operation of the system focuses on the manpower and personnel requirements for Aquila. There are two basic issues here: the number of personnel required for manning the system, and the aptitudes required for performing the various tasks associated with operating the system.

Information from OT II and an independent analysis of manpower, personnel and training issues (U.S. Army Research Institute, 1987) indicated that, with respect to the number of personnel required, Aquila was far more manpower intensive than originally planned.

Operations manpower had its own set of problems. For example, the OT II test criterion for preparing and launching an air vehicle after receiving a mission order was a maximum of 60 minutes on 80% of the trials. However, the time criterion was met on only 44% of the trials. Part of the failure to reach criterion can be attributed to the high number of launches that were aborted because of maintenance problems indicated by the Built-In Test (BIT) system. In fact, throughout OT II an average of 2.2 launch attempts were made for every successful launch. Nevertheless, the eight man launch and recovery section was usually able to handle adequately the launch when equipment did not malfunction, and in many cases got a launch off in ten minutes. However, the OT II only tested operations during daylight hours. As mentioned earlier, the Army plans to include a FLIR payload on future UAVs and thus provide a 24-hour continuous operations capability. Given the high degree of equipment malfunction that kept crews busy, and the requirement to operate around-the-clock, one is logically led to ask whether an eight-man crew could continue to function adequately for very long. Perhaps two four-man crews could, by working 12-hour shifts, but then one must consider that many other duties arise in combat, such as perimeter security. Unfortunately, no data were collected on this very important manpower problem during any of the tests, but the SRL Task Force plans to examine it in evaluating future UAV systems.

A related question that emerged, (and also one on which data are scarce), concerned the skills and aptitudes required for operating Aquila. A basic problem existed in that the skills required to operate a system like Aquila were distinct enough to require a unique military occupational specialty (MOS). However, since it was not a high volume system (the Army only planned to acquire nine Aquila batteries requiring about a thousand troops), the density of the MOS was low. This situation was complicated by the fact that soldiers with the Aquila MOS were assigned to one of two distinct jobs: either operating the launch and recovery system, where requirements were rather physical, or operating the control station, where requirements were more cognitive and perceptual. It could be argued that two MOSs should have been created for these jobs, but doing so would have meant that each MOS would contain only 400-600 troops, a very low density indeed. The Army personnel system has difficulty managing low density MOSs. The situation was compounded by the fact that little empirical data existed on the types of aptitudes actually required for operating the control station, so it was difficult to make a firm decision as to whether or not that job should require a distinct MOS. An alternative to the creation of a separate MOS is the designation of an additional skill identifier to differentiate those personnel whose job is handling heavy equipment from those who perform primarily cognitive tasks. These are fundamental issues to be addressed in future UAV MANPRINT efforts.

Maintainer-Related MANPRINT Concerns

Estimating Maintenance Manpower Requirements

HARDMAN analysis. In addition to the operations manpower problems mentioned in the preceding section, evidence of potential maintenance manpower difficulties arose in conjunction with DT II and OT II. This phase of the Aquila MANPRINT Task Force effort was concerned with the application of an analytical method for forecasting manpower requirements, and the impact of poor performance of the electronic fault isolation equipment during OT II on the accuracy of manpower estimates.

Hardware vs. manpower (HARDMAN) and its automated derivative, HARDMAN II are methods for estimating MPT requirements for emerging systems. HARDMAN was performed on the Lockheed Aquila RPV for the Field Artillery School TRADOC Systems Manager under contract with Jet Propulsion Laboratory (Dynamics Research Corporation, 1983). The original analysis assumed that the RPV battery would be fielded in five autonomous sections, and that the operational scenario would be a 12-hour day.

The 1985 revision of the Target Acquisition, Designation and Aerial Reconnaissance System (TADARS) RPV Operational and Organizational (O&O) Plan imparted more centralization and control to the Aquila battery. Originally, the battery was to consist of five autonomous sections, each with the full capability of launching, piloting, recovering and maintaining a total of five air vehicles (AVs); in short, a section could conduct a complete mission on its own. This arrangement was superseded by a more centralized battery, consisting also of five sections, none of which was fully autonomous. The Aquila battery now consisted of three Forward Control Sections (FCSs) and two rear area Centralized Launch and Recovery Sections, (CLRSs) each with its own Ground Control Station. Each CLRS would have a Launch Subsystem, Recovery Subsystem, Air Vehicle Handler and five AVs. It was the responsibility of the two CLRSs to conduct launch and recovery operations for the entire battery. After the AV was launched, it was to be handed off to a FCS, which controlled the aircraft as it carried out its mission. The AV was to be handed off to a CLRS for recovery upon completion of its mission. Only one CLRS, the Primary CLRS (or CLRS 1) was to have a maintenance shelter (MS) along with three spare AVs. The MS and its crew of four were to provide organizational level maintenance for all 13 AVs. Originally, it was intended that each CLRS have a MS. Figure 1 illustrates the employment of the Aquila battery under the CLRS O&O Plan.

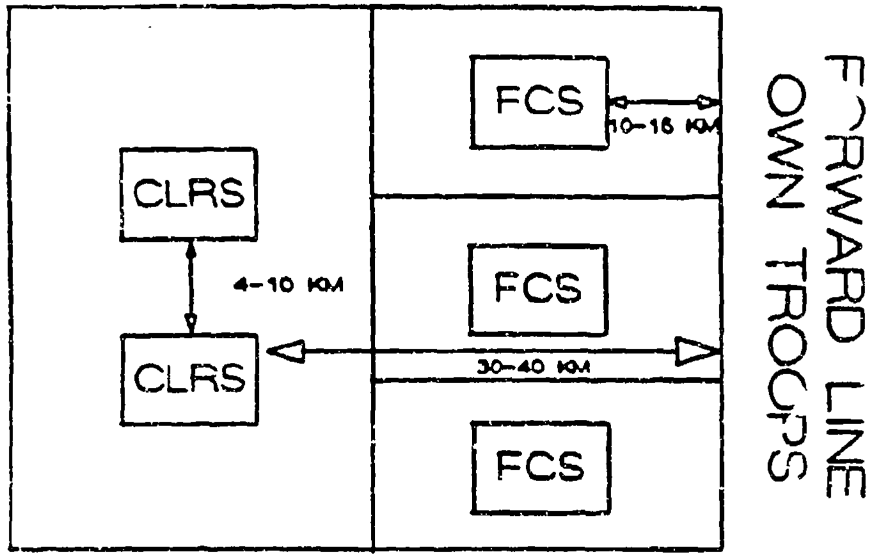

Figure 1. Aquila battery employment.

Analysis of the original HARDMAN was required to incorporate these changes. One principal finding of the revised HARDMAN (Dynamics Research Corporation, 1985) was that, because of the shift from a 12 to a 24 hour operational scenario, six MOS 13T PS maintainers were required at the MS instead of the four required by the 1985 TADARS O&O Plan.

Sensitivity analysis. However, lower than expected automatic fault isolation (FI) rates obtained by the automated test equipment (ATE) during DT II in 1986 and OT II in 1987 indicated that maintenance manpower requirements should be readdressed. Also, it appeared that single point estimates of ATE performance were not as useful as a range of estimates based on expected levels of ATE performance.

In an investigation of another Army system, Stewart and Shvern (1988) applied HARDMAN II sensitivity analysis to two components of the Forward Area Air Defense system. Maintenance manpower estimates as a function of automatic fault isolation performance caused the Army to reexamine its original maintenance manpower requirements. Similarly, the Aquila sensitivity analysis was performed in order to provide the Army with updated information about maintenance requirements for the Aquila RPV, and to illustrate further its efficacy as an adjunct to HARDMAN and its derivatives.

Method

Documentation. The principal data sources were the 1983 and 1985 HARDMAN analyses. The 1985 TADARS O&O Plan (with changes)

provided information on projected repair times, usage rates, and operational scenarios. Test data were available from DT II and OT II which provided information on maintenance ratios, the number of repair actions at organizational and intermediate levels, and operational availability estimates from these tests.

The Required Operational Capabilities (ROC) document called for a successful fault isolation (FI) rate of 90%. Generally, ATE performance to date has been poorer than this (see Nauta, 1985). During Development Test II (Cozby, 1986), the Aquila ATE system only isolated 35% of all faults. During Operational Test II (OTEA, 1987) this rate was slightly less than 20%.

Analytical approach. The methodology employed in the present analysis was a "top-down" approach which relied on HARDMAN results as a baseline. Because detailed raw data from the HARDMAN were not available, it was necessary to rely on data from DT II and OT II to obtain estimates of AV down time, repair times and maintenance ratios. The wartime operational scenario from the 1985 TADARS O&O Plan allowed for extrapolation to the total RPV battery. The resultant annual maintenance manhours (AMMH) obtained through the top-down approach (7722) agreed closely with those from the HARDMAN (7961 adjusting for the 24 hour scenario). Mean Time to Repair (MTTR) times using ATE from the revised O&O Plan are wrench-turning times only. Using the ATE, these were: 30 min by day and 45 min by night. Manual MTTRs were 90 min (day) and 135 min (night).

The ATE system is mounted inside the MS. For diagnoses of faults to be carried out, the AV must be partially disassembled, defueled, and then moved inside the shelter, accounting for the day-night differences in MTTR.

Operational scenarios. Total AV operating hours for the 24 hour-25 mission scenario would be 54 hours, based on the 1985 TADARS O&O Plan.

Maintenance ratios. From operational requirements and OT II test results it can be inferred that 1.27 maintenance actions per day will be required per air vehicle.

Effects of travel. For the remote CLRS, there should be 6.35 maintenance actions per day anticipated. It is assumed that two maintainers from the maintenance shelter will retrieve the AV.

Results and Discussion

The sensitivity estimates are presented in Table 1. Dependent variables are annual maintenance manhours (AMMH), final maintenance ratio (FMR), operational availability (A_o), number of mission-ready AVs and maintenance man years (MMY). Independent variables are (a) ATE fault isolation (FI) rates of 90% (similar

to the ROC requirement), 40% (slightly better than at DT II) and 20% (similar to OT II), (b) percentage of repairs performed during daytime hours (50% or 80%) and (c) distance between CLRS 1 and 2. Distance between CLRS=0 is equivalent to there being two MSs.

Table 1

Aquila RPV Maintenance Sensitivity Analysis

	Distance Between Primary and Secondary CLRS (Km)						
	0	4	6	8	10	12	14
ATE FI = 90%							
(50% daytime repairs)							
AMMH	7961	8579	8888	9197	9506	9815	10124
FMR	.40	.44	.45	.47	.48	.50	.51
A_O	.60	.56	.54	.53	.52	.50	.49
AVs	7.75	7.34	7.13	6.93	6.72	6.52	6.32
MMY	3.32	3.57	3.70	3.83	3.96	4.08	4.22
(80% daytime repairs)							
AMMH	5998	6464	6697	6938	7188	7447	7715
FMR	.30	.33	.34	.35	.36	.38	.39
A_O	.70	.66	.66	.65	.64	.62	.61
AVs	9.10	8.58	8.58	8.45	8.28	8.06	7.93
MMY	2.50	2.69	2.69	2.89	2.98	3.10	3.21
ATE FI = 40%							
(50% daytime repairs)							
AMMH	13988	14605	14915	15224	15533	15824	16151
FMR	.71	.74	.76	.77	.79	.80	.82
A_O	.29	.26	.24	.23	.22	.20	.18
AVs	3.77	3.38	3.12	2.99	2.86	2.60	2.34
MMY	5.82	6.08	6.21	6.34	6.47	6.60	6.72

Table 1 (Continued)

Aquila RPV Maintenance Sensitivity Analysis

	Distance Between Primary and Secondary CLRS (Km)						
	0	4	6	8	10	12	14
ATE FI = 40%							
(80% daytime repairs)							
AMMH	10966	11818	12243	12684	13141	13614	14104
FMR	.56	.60	.62	.64	.67	.69	.72
A_O	.44	.40	.38	.36	.33	.31	.28
AVs	5.72	5.20	4.94	4.68	4.29	4.03	3.64
MMY	4.57	4.92	5.10	5.29	5.48	5.67	5.88
ATE FI = 20%							
(50% daytime repairs)							
AMMH	16398	17016	17325	17634	17943	18252	18561
FMR	.83	.86	.88	.90	.91	.93	.94
A_O	.17	.14	.12	.10	.09	.07	.06
AVs	2.18	1.82	1.56	1.30	1.17	.91	.78
MMY	6.83	7.09	7.22	7.35	7.48	7.61	7.73
(80% daytime repairs)							
AMMH	12963	13969	14993	15201	15534	16093	16672
FMR	.66	.71	.77	.76	.79	.82	.85
A_O	.34	.29	.24	.23	.21	.18	.15
AVs	4.42	3.77	3.38	2.99	2.73	2.34	1.95
MMY	5.40	5.82	6.25	6.33	6.47	6.71	6.95

Conclusions

Maintenance support of the Aquila would have posed no problem if the ATE system were to have performed as specified in the O&O Plan. The sensitivity analyses showed that for ATE FI rates of 90%, the maximum mission requirement (of five AVs airborne at any one time) could have been met with the maintenance manpower resources available. Neither repair scheduling, the number of MSs, nor distance between CLRS would have posed a threat to operational capability.

Were FI rates to fall to 40%, the five-AV requirement could still be met under optimal conditions (80% daytime repairs and two MSs); with only one MS, the CLRSs must be no farther than 4 km apart in order to meet the requirement.

If FI rates approximated OT II results (20%), the mission requirement could not be met, regardless of assets or scheduling of repair times.

It should be noted that estimates for the present project agree closely with findings of the draft Human Factors Engineering Analysis (Human Engineering Laboratory, 1987) which found that during OT II the MS crew of a battery "minus" had difficulty keeping up with the workload for a single CLRS. The report also expressed doubt that the MS crew would be able to support an entire Aquila battery. If operational requirements of the Aquila are to be met at all, an FI rate of at least 40%, which is slightly higher than that attained at OT II, must be achieved, along with the acquisition of an additional MS for each battery.

The present analysis further underscores the usefulness of sensitivity analysis, which enhances the effectiveness of HARDMAN II. The uncertain performance of ATE and other electronic fault diagnostics make single point estimates, based on optimistic criteria, impractical.

General Discussion

Lessons Learned

Succinctly, it can be stated that the Aquila MANPRINT Task Force's intervention came too late to save a foundering system from cancellation. In spite of this, major MANPRINT problems relating to the operation and maintenance of Aquila were pinpointed, painstakingly analyzed, and concrete recommendations were made which should provide valuable lessons for those involved in the development of the current family of UAVs. These recommendations illustrated that some MPT problems can be alleviated or at least minimized without requiring expensive redesign of the system. In fact, with the exception of the imaging system it itself, the difficulties encountered appeared to be attributable more to MPT than to inherent hardware design problems.

In addition, the effectiveness of sensitivity analysis as a useful adjunct to HARDMAN and HARDMAN II was demonstrated. One important lesson that carried over from applications of the technique to other systems (Stewart & Shvern, 1988) was that performance specifications for BIT and ATE equipment, at least with regard to many new and recently-fielded Army systems, may be too rigourous. Consequently, the results of HARDMAN II analyses

that assume high levels of BIT and ATE performance become suspect when DT and OT results show much lower levels. This is a cogent argument for providing a range of manpower estimates based upon a band of BIT or ATE isolation rates. In such a way decision-makers can determine the minim lly acceptable level of performance that would allow the system to be field within the stipulated manpower constraints that are now imposed by TRADOC.

In Retrospect

In brief, what the ARI MANPRINT Task Force has learned from its experience with Aquila is itself a good argument for MANPRINT. The Aquila had a protracted developmental history during which many MPT and some system design problems were encountered. One major requirement for successful MANPRINT intervention is timeliness, and it appears that for Aquila, the MPT problems could and should have been addressed much earlier. Had they been, the fate of Aquila may have been quite different. Still, it is reasonable to suppose that similar problems will be encountered with the UAV Close system, Aquila's successor, which is currently under development. Now is the time to identify, attack, and resolve these problems.

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